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Models are a "metaphor in your brain": How potential and preservice teachers understand the science and engineering practice of modeling

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Abstract
We investigated beginning secondary science teachers' understandings of the science and engineering practice of developing and using models. Our study was situated in a scholarship program that served two groups: undergraduate STEM majors interested in teaching, or potential teachers, and graduate students enrolled in a teacher education program to earn their credentials, or preservice teachers. The two groups completed intensive practicum experiences in STEM-focused academies within two public high schools. We conducted a series of interviews with each participant and used grade-level competencies outlined in the *Next Generation Science Standards* to analyze their understanding of the practice of developing and using models. We found that potential and preservice teachers understood this practice in ways that both aligned and did not align with the *NGSS* and that their understandings varied across the two groups and the two practicum contexts. In our implications, we recommend that teacher educators recognize and build from the various ways potential and preservice teachers understand this complex practice to improve its implementation in science classrooms. Further, we recommend that a variety of practicum contexts may help beginning teachers develop a greater breadth of understanding about the practice of developing and using models.

KEYWORDS
STEM education, science and engineering practices, teacher knowledge, teacher education, standards, teachers and teaching

1 | INTRODUCTION

In the United States, the recent *Next Generation Science Standards* [*NGSS*] (NGSS Lead States, 2013) differ from previous science education standards (National Research Council [NRC], 1996) in that they specify eight science and engineering practices rather than emphasize the general notion of "scientific inquiry" (NRC, 1996, p. 23). This focus on science and engineering practices provides a clearer common language for science educators, better describes the nature and work of science and engineering, and facilitates construction of more detailed goals for what students should experience and learn (Osborne, 2014). According to Bybee (2011), the shift from inquiry to practices "will likely be one of the most significant challenges for the successful implementation of [the new] science education standards" (p. 39). As the *NGSS* are more widely implemented, there emerges a need to investigate the ways science teachers attempt to

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integrate science and engineering practices into their understanding and instruction.

One practice that is particularly challenging for science teachers to fully understand and implement is developing and using models (Khan, 2011; Schwarz & Gwekwerere, 2007; Windschitl & Thompson, 2006). Yet, the work of science and engineering is primarily about modeling (Passmore, Coleman, Horton, & Parker, 2013; Passmore, Stewart, & Cartier, 2009). In science, models represent systems and have both explanatory and predictive power. In engineering, they are used to test solutions to an engineering design problem. Across both science and engineering, models take different forms depending on how they will be used and the system or part of a system under study.

We investigated beginning secondary science teachers' understandings about the *NGSS* science and engineering practice of developing and using models. Our study was situated in a scholarship program at a large public research university in California. This program served two groups: undergraduate majors from physics, chemistry, and engineering who were interested in exploring teaching as a career, herein referred to as *potential teachers*, and graduate-level chemistry, physics, and engineering credential candidates enrolled in a post-baccalaureate teacher education program, herein referred to as *preservice teachers*. The scholarship program offered an internship for potential teachers and the field experience component of the teacher education program for preservice teachers. Both these practicum opportunities were in physical science and engineering classrooms situated within two STEM-focused academies. Half of the potential and preservice teachers were placed in an academy with an engineering focus, while the other half were placed in an academy with an environmental science focus.

The following two research questions guided our study: What did potential and preservice teachers understand about the *NGSS* science and engineering practice of developing and using models and how did their understandings align (or not) with the *NGSS*? What similarities and differences in understandings were visible across (a) potential and preservice teacher groups and (b) the two practicum contexts?

2 | THEORETICAL FRAMEWORK

Our research is framed by a situated perspective on teacher learning which foregrounds the contextual and social aspects of learning. Situated learning considers that all learning occurs in a context and that the context, associated activity, and tools contribute to what is learned (Brown, Collins, & Duguid, 1989; Greeno, 2006; Lave & Wenger, 1991; Putnam & Borko, 2000). Learning is conceptualized as increased participation in a community's practices, and an individual's development and use of knowledge as a result of participating in that community. In this study, the practicum experiences were distinct social learning environments where the potential and preservice teachers interacted with mentor teachers and their K–12 students. They observed and participated in teaching that included implementation of the *NGSS* science and engineering practices. As such, we considered the practicum experiences as opportunities for potential and preservice teachers to develop knowledge about teaching, in general, and the *NGSS* science and engineering practices, in particular.

A situated view of teacher learning also foregrounds views of learning to teach as a continuum that spans a teacher's career. Feiman-Nemser (2001) identified initial preparation, induction, and professional development as the three stages of the teacher learning continuum; each stage has unique challenges and needs, but all involve continuing growth and development. In this study, we examined the understandings of beginning teachers at two points in the initial preparation phase—undergraduate-level potential teachers and graduate-level preservice teachers. Although both groups are in the initial preparation phase, we consider them to be distinctly different. Potential teachers are at the beginning stages of exploring teaching as a career but have not yet committed to teaching. There is a lack of research on potential teachers and introductory practicum experiences that acquaint them with classroom teaching. In contrast, preservice teachers have committed to pursuing teaching as a career, are working toward degrees or credentials specifically for teaching, and have often completed preprofessional practicum experiences. As beginning teachers in different stages of initial teacher preparation, we expected their understandings and needs related to the practice of developing and using models to be different. It is important for both researchers and teacher educators to know what teachers at different stages on the continuum understand about developing and using models and how to build from that understanding to improve classroom implementation of this practice.

3 | LITERATURE REVIEW

3.1 | The practice of developing and using models

Models are used in science to visualize and make sense of phenomena, and in engineering, to develop and test possible design solutions (Krajcik & Merritt, 2012). Scientists use models to generate questions and construct explanations of phenomena, including underlying mechanisms, causal links, and functions. Scientists make predictions using models to test proposed explanations, and then evaluate and refine models by iteratively comparing predictions to real-world occurrences. As such, scientific models are based on evidence and modified in light of new evidence (NGSS Lead States, 2013; NRC, 2012; Schwarz et al., 2009). Engineers, in comparison, use models to analyze existing systems and determine strengths and limitations of designs (NRC, 2012). In both science and engineering, models are approximations and simplifications that highlight certain features of phenomena or systems while obscuring or minimizing others (Krajcik & Merritt, 2012; NRC, 2012; Schwarz et al., 2009).

Model-based science instruction has been shown to positively impact student learning (Jackson, Dukerich, & Hestenes, 2008). Using models as a basis for school science investigations provides a more authentic experience of science, particularly compared to investigations based on the traditional scientific method (Passmore et al., 2009; Windschitl, Thompson, & Braaten, 2008). Indeed, developing and using models has been proposed as an anchor for engaging students in the other seven practices outlined in the *NGSS* (Passmore et al., 2013, 2009). The practice of modeling can also be used to provide students with greater insights into engineering disciplines. For example, model eliciting activities used in K–12 classrooms and undergraduate engineering courses provide students with a real-world problem where they are asked to develop an effective mathematical model, physical prototype, or analytical model that solves the problem and can be applied to similar problems (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004; English & Mousoulides, 2011).

3.2 | Teachers' understanding and implementation of developing and using models

Previous studies have explored science teachers' understanding of models and modeling. As one example, Windschitl and Thompson (2006) examined preservice secondary teachers' conceptions of the nature and function of models and how these preservice teachers used models in their own investigations in the context of a methods course with an instructional focus on models. Although the preservice teachers developed more sophisticated conceptions about the nature and function of models by the end of the course, they struggled to develop and use models in their own investigations. Further, certain aspects of their understanding changed more than others: More preservice teachers began to think of models as predictive tools, but fewer recognized the conjectural nature of models or viewed models as a part of scientific investigations. Overall, preservice teachers readily recognized models as ways to illustrate or communicate information, but were less apt to recognize models as tools used in scientific inquiry.

Additional studies have documented teachers' challenges with implementing the practice of modeling in science instruction. Schwarz and Gwekwerere (2007) investigated how preservice elementary teachers incorporated models into lesson plans after completing a methods course focused on model-based inquiry. They found that preservice teachers more often used modeling to illustrate phenomena or represent patterns in data rather than to engage students in constructing and evaluating models. Khan (2011) conducted a case study of four practicing secondary science teachers' implementation of model-based teaching strategies following professional development in model-based teaching. Khan found that although the teachers frequently asked students to develop initial models of phenomena, they seldom engaged students in comparing, evaluating, and modifying these initial models. The teachers also rarely made individual students' models public to the class, discussed the explanatory power of models, or expanded on specific relationships within models. Similarly, Miller and Kastens (2018) found that the two teachers in their study initially used models didactically, as tools for demonstration, but after targeted professional development were able to engage students with models as problem-solving tools.

Clearly, engaging students in developing and using models in science and engineering classrooms is a complex task (Schwarz et al., 2009). *A Framework for K–12 Science Education* [*Framework*] (NRC, 2012) suggests major goals, or *competencies*, for the practice of modeling that students should achieve by the end of grade 12, along with a proposed progression of how these competencies might develop across the grade levels. In the *NGSS*, this progression of competencies is expanded and further defined in the Practices Matrix (NGSS Lead States, 2013, Appendix F). Although several studies have shown that teachers struggle in their understanding and implementation of the practice of developing and using models, no studies have examined how teachers' understanding of this practice aligns with the competencies outlined in the *NGSS*. In our study, we used the *NGSS* competencies to characterize potential and preservice teachers' understanding of this practice.

4 | STUDY DESIGN AND METHODS

In line with our research questions, we conducted a qualitative comparative case study (Merriam & Tisdell, 2016) because our goals were to understand participants' ideas and to compare them across practicum contexts and participant groups. We considered each practicum context to be a bounded case, and embedded within each case, two types of participants, potential and preservice teachers.

4.1 | Study context

4.1.1 | Practicum experiences

As introduced above, this study was situated in a scholarship program. In the second year of program implementation (2014–2015), eight potential teachers and four preservice teachers were placed in the unique classroom contexts of STEM academies to learn to teach science and engineering in innovative ways. Four potential and two preservice teachers were placed at one high school's academy, The Project-Based Engineering Academy. The other four potential and two preservice teachers participated in a second high school's academy, The Green STEM Academy. All mentor teachers at both academies were credentialed teachers. Most mentor teachers had 10–15 years of teaching experience, one had 25 years of experience, and one had five years of experience.

The undergraduate potential teachers completed a five-week intensive internship in academy classrooms at the beginning of the school year. Since the academic year at the university where the potential teachers were enrolled started five weeks after the K–12 school year began, potential teachers were able to participate in high school classes five days a week for five weeks. They also attended a weekly seminar during these five weeks where they discussed their experiences in classrooms and received introductory instruction on ways to effectively teach science and engineering to secondary students, including an overview of the eight science and engineering practices from the *NGSS* (NGSS Lead States, 2013). These potential teachers were invited to continue their participation in classrooms throughout the rest of the academic year, although continued participation was not required.

The graduate-level preservice teachers participated in academy classrooms as part of the field experience component for their teacher education program. Preservice teachers were enrolled in a 13-month, post-baccalaureate teacher education program to earn a credential in chemistry, physics, and/or engineering, and if they elected, a master's in education. Throughout the credential program, they were required to participate in secondary school classrooms and complete university coursework. Coursework included three science teaching methods courses: The first was specifically about the *NGSS*, including a weeklong focus on the practice of developing and using models; the second continued to emphasize the *NGSS* science and engineering practices; and the third focused on *NGSS*-aligned instruction for English learners.

4.1.2 | The academies

The Project-Based Engineering Academy (PBEA), the context of one case, served grades 9–12 at Mountain High School. Students were admitted into the program in grade 9 through a competitive application and interview process and then continued in the academy as a cohort through grade 12. A team of PBEA teachers collaboratively designed and implemented the curriculum, which was organized around authentic engineering projects and spanned instruction in physics, computer-aided design (CAD), art, and machining. Each of these four subjects was taught in a dedicated classroom by a different credentialed teacher. Students rotated through these four spaces multiple times throughout the academic year. Individual engineering projects in grades 9 through 11 (e.g., a mobile, a light box sculpture, and a Moiré kinetic light sculpture) prepared students for a collaborative senior capstone project. Students completed their other classes at the adjoining high school.

The Green STEM Academy (GSA), the context of the second case, was located at Mission High School and offered students courses in environmental education. GSA was a less formal program than PBEA: There was no application process and courses were open to all of the high school's students. Study participants were placed in either Green Chemistry classes or Green Engineering and physics classes. In Green Chemistry, environmental issues (e.g., climate change, oil spills) were incorporated into a traditional chemistry curriculum. In Green Engineering, students engaged in environmentally focused engineering projects (e.g., a solar-powered toy car). The physics classes were not part of the academy, but were taught by the Green Engineering teacher.

4.2 | Study participants

4.2.1 | Potential teachers

Table 1 shows demographic information for the eight potential teacher participants. During the five-week intensive internship, the four potential teachers placed at PBEA participated in all aspects of the integrated curriculum: They were exposed to the physics, CAD, art, and machining spaces and interacted with four mentor teachers. For the four potential teachers placed at GSA, two were placed in both physics and Green Engineering classes with one mentor teacher, and the other two were placed in Green Chemistry classes with a second mentor teacher. Six of the eight potential teachers continued to participate in classrooms throughout the academic year (September to June) to varying degrees. Although not required as part of their internship, five potential teachers enrolled in at least one education course before the five-week intensive internship or during the subsequent academic year.

4.2.2 | Preservice teachers

Demographic information for the preservice teachers is also shown in Table 1. Three of the preservice teacher participants completed yearlong student teaching field experiences in academy classrooms, two at PBEA, and one at GSA in chemistry. One preservice teacher, Tom, completed the first half of his field experience at GSA in physics and Green Engineering and the other half at a different high school. The two preservice teachers placed at PBEA primarily participated in the physics space.

TABLE 1 Potential teacher and preservice teacher demographic information

	Teacher	Placement	Major/Credential(s) pursued*	Ethnicity	Gender
Undergraduate potential teachers	Erica	PBEA	Physics	European American	Female
	Josiah	PBEA	Physics	European American	Male
	Letitia	PBEA	Mechanical Engineering	Mexican American	Female
	Sadie	PBEA	Computer Science	Chinese American	Female
	Quentin	GSA—Physics/Green Engineering	Physics	Chinese American	Male
	Sung	GSA—Physics/Green Engineering	Physics	Korean American	Male
	Cameron	GSA—Chemistry	Chemistry	European American	Male
	Paulina	GSA—Chemistry	Chemistry	Filipina American	Female
Graduate preservice teachers	Kevin	PBEA	Physics/Industrial Technology[a]	European American	Male
	Kurt	PBEA	Physics/Industrial Technology[a]	European American	Male
	Tom	GSA—Physics/Green Engineering	Physics	European American	Male
	Beth	GSA—Chemistry	Chemistry	European American	Female

[a]The Industrial Technology credential allowed physics teachers to teach engineering courses after graduation.

*Table shows undergraduate major for potential teachers and credential(s) pursued for preservice teachers at the time of data collection.

4.3 | Data collection

For this qualitative case study, we conducted a series of interviews with each potential and preservice teacher. We used interviews as a data source because, according to Brenner (2006), qualitative interviews attempt to “understand informants on their own terms” (p. 357). We interviewed undergraduate potential teachers four times: before and after their five-week internship, mid-academic year, and at the end of the academic year. We interviewed graduate preservice teachers three times: before their field placement, mid-academic year, and at the end of the academic year. We conducted all interviews using a semi-structured protocol (Brenner, 2006). For each interview, participants were presented with eight cards, with an *NGSS* practice written on each, as prompts for discussion. Participants were asked to define each practice, identify the practices they had seen and/or implemented during their practicum experiences, and provide examples of each practice observed. As this study was part of a larger research project, other questions besides those related to the practices were included in the interviews as well.

4.4 | Data analysis

To begin the analytic process, all interviews were transcribed by either a researcher or a professional service and then checked by another researcher for accuracy. We first coded all transcripts for each of the eight science and engineering practices (NGSS Lead States, 2013). From this coding, we determined that participants more often expressed confusion about the practice of developing and using models than the other practices. We decided to narrow our focus to this practice for the remainder of our analysis.

We isolated all transcript excerpts related to the practice of developing and using models. We then coded these excerpts using an a priori coding scheme based on the grade-level competencies outlined in the *NGSS*. In other words, to determine the depth and breadth of participants’ understanding of the practice of modeling, we created descriptive codes (Saldaña, 2013) based on the Practices Matrix from *NGSS*’s Appendix F (NGSS Lead States, 2013). For each science and engineering practice, the Practices Matrix lists “the specific capabilities” that students should acquire by the end of grade bands K–2, 3–5, 6–8, and 9–12 (p. 49). Rather than using the term capabilities, the *Framework* outlines the major competencies that students should acquire for each practice by the end of grade 12 (NRC, 2012, p. 49). For clarity, we decided to use the term competencies to refer to the individual elements of the Practices Matrix and to our coding scheme. As an example of how the Practices Matrix was used in another study, Kang, Donovan, and McCarthy (2018) used competencies from the K–2 grade band in a survey format to measure elementary teachers’ perceived levels of knowledge and confidence about teaching the eight practices and teachers’ pedagogical content knowledge of the eight practices.

More specifically, we developed the coding scheme based on the competencies listed under each of the four grade bands, a total of 22 competences in all. Although participants were placed in grades 9–12 classrooms, we included codes from lower grade bands to determine the range of participant understandings. Since competencies build on each other across grade bands (NGSS Lead States, 2013), while a participant might have expressed an understanding that was not fully aligned with a grade 9–12 competency, it might be aligned with a similar competency at a lower grade band. In our coding scheme, a code indicated the grade band and specific competency. For example, code 3-5.1 was used to indicate grade band 3-5, competency number 1: "Identify limitations of models" (NGSS Lead States, 2013, Appendix F, p. 53). These competency codes are shown in Table 2. In addition to the competency codes, we included the code *not aligned*, which was applied if a participant referred to the practice of developing and using models in a way that did not fit with any of the competencies included in the Practices Matrix. Excerpts that were too short to provide insight into a participant's conception of the practice were not coded. An excerpt could receive more than one code, if more than one competency was expressed in that excerpt.

To ensure the trustworthiness (Brenner, 2006) of our analysis, we collectively designed the coding scheme and practiced coding with a sample of the data until consistency was reached. We then independently coded the remaining data, compared our codes, and resolved any coding differences through discussion until consensus was reached. We also used focus group interviews with the mentor teachers for data triangulation. Through these interviews, we ensured that the mentor teachers implemented the practice of developing and using models in ways that were aligned with the *NGSS*.

We analyzed all interviews for each participant. Since the number of interviews varied across participant types (potential and preservice teachers) and because a given participant could have more than one excerpt coded with a certain code, we aggregated counts of codes across excerpts for each participant. In other words, we counted a code as present or absent across all interviews for a given participant. Thus, we present findings as the number of participants who had at least one excerpt that fit with a given code. This allowed us to determine the number of participants who had ideas about the practice of developing and using models that resonated with individual *NGSS* competencies and the number of participants who had ideas that did not align with the *NGSS*. We did this to compare and contrast understandings across participant type (potential vs. preservice teachers) and practicum context (PBEA vs. GSA).

5 | FINDINGS

5.1 | Finding set 1: Potential and preservice teachers' understanding of the *NGSS* science and engineering practice of developing and using models

We found that the potential and preservice teacher participants described the practice of developing and using models in multiple ways. Of the 22 modeling competencies in our coding scheme (see again Table 2), participants described this practice in ways that aligned with 16 of them. Participants also described this practice in ways that did not fit with any of the competencies, as indicated by the not aligned code. Figure 1 displays the number of potential and preservice teachers with excerpts coded at each code.

To provide greater insight into the range of participants' understanding of developing and using models, we present examples of how participants described this practice from each grade band and from the not aligned code category. For the K–2 grade band, 4 of the 12 participants described models in line with the competency K–2.3: "Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s)" (NGSS Lead States, 2013, Appendix F, p. 53). For example, Sadie, a potential teacher placed at PBEA, described how she had made physical models of cells in her high school biology class to represent relative scale and structure. In her initial interview, she explained, "We made cells …. Like, 'Oh, I need to make this. I need to make a nucleus, but how am I supposed to put it inside this big circle cell?'" As another example, Sung, a potential teacher placed at GSA, recounted an example of using vectors in his practicum experience:

> So setting the origin, drawing the diagram, so students can visualize the problem better …. If a boat was in the water, then the boat will go [at] the velocity caused by the river and the velocity caused by the boat …. And [my mentor teacher] will make the students draw out both the velocities and the final superposition velocity.

In these two examples, the potential teachers described developing and using physical models and diagrams as ways to show relative scales and relationships, as aligned to competency K–2.3.

From the 3–5 grade band, three participants described models in line with competency 3-5.3: "Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution" (NGSS Lead States, 2013, Appendix F, p. 53). For example, Paulina, a potential teacher placed at GSA, described a model as "a metaphor in your brain …. It doesn't have to be something that's physically here for you to understand it, but also if you think of it in another way, like as a metaphor." As another example, Erica, a potential teacher placed at PBEA, described the practice of modeling as "thinking of a science phenomenon through, instead of just the equation, [also as] an example of its applicability." In these two examples, the potential teachers understood that models are not always physical or mathematical models but can be more abstract representations,

TABLE 2 Competency codes for the practice of developing and using models by grade band

Grade band	Competencies
Grades K–2	1. Distinguish between a model and the actual object, process, and/or events the model represents. 2. Compare models to identify common features and differences. 3. Develop and/or use a model to represent amounts, relationships, relative scales (bigger, smaller), and/or patterns in the natural and designed world(s). 4. Develop a simple model based on evidence to represent a proposed object or tool.
Grades 3–5	1. Identify limitations of models. 2. Collaboratively develop and/or revise a model based on evidence that shows the relationships among variables for frequent and regular occurring events. 3. Develop a model using an analogy, example, or abstract representation to describe a scientific principle or design solution. 4. Develop a diagram or simple physical prototype to convey a proposed object, tool, or process. 5. Use a model to test cause and effect relationships or interactions concerning the functioning of a natural or designed system.
Grades 6–8	1. Evaluate limitations of a model for a proposed object or tool. 2. Develop or modify a model, based on evidence, to match what happens if a variable or component of a system is changed. 3. Use and/or develop a model of simple systems with uncertain and less predictable factors. 4. Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. 5. Develop and/or use a model to predict and/or describe phenomena. 6. Develop a model to describe unobservable mechanisms. 7. Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs, and those at unobservable scales.
Grades 9–12	1. Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria. 2. Design a test of a model to ascertain its reliability. 3. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. 4. Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations. 5. Develop a complex model that allows for manipulation and testing of a proposed process or system. 6. Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

such as analogies/metaphors or examples that describe phenomena, as aligned to competency 3-5.3.

From the 6–8 grade band, six participants described the practice of modeling in ways that resonated with competency 6-8.5: "Develop and/or use a model to predict and/or describe phenomena" (NGSS Lead States, 2013, Appendix F, p. 53). For example, GSA preservice teacher Beth emphasized that a model must be used to predict. In her midyear interview, she explained that a model "has to then be used to apply to something …. A graphical representation isn't a model unless it can predict or be used to apply something." Similarly, in her final interview, Beth stated, "I define a model not as a representation but something that you would use to apply to a new situation …. It's a representation unless it can be used to predict something." Beth's emphasis on using models to predict phenomena aligns with competency 6-8.5.

From the 9–12 grade band, three participants described models in line with competency 9-12.5: "Develop a complex model that allows for manipulation and testing of a proposed process or system" (NGSS Lead States, 2013, Appendix F, p. 53). For example, in his interview after the five-week internship, potential teacher Cameron recalled a discussion related to models that he had with a high school student in his GSA chemistry practicum experience:

> We were having a bit of a discussion about the black boxes … and I think I asked something along the lines of, "How do we figure out if this is really what's going on inside the box?" And

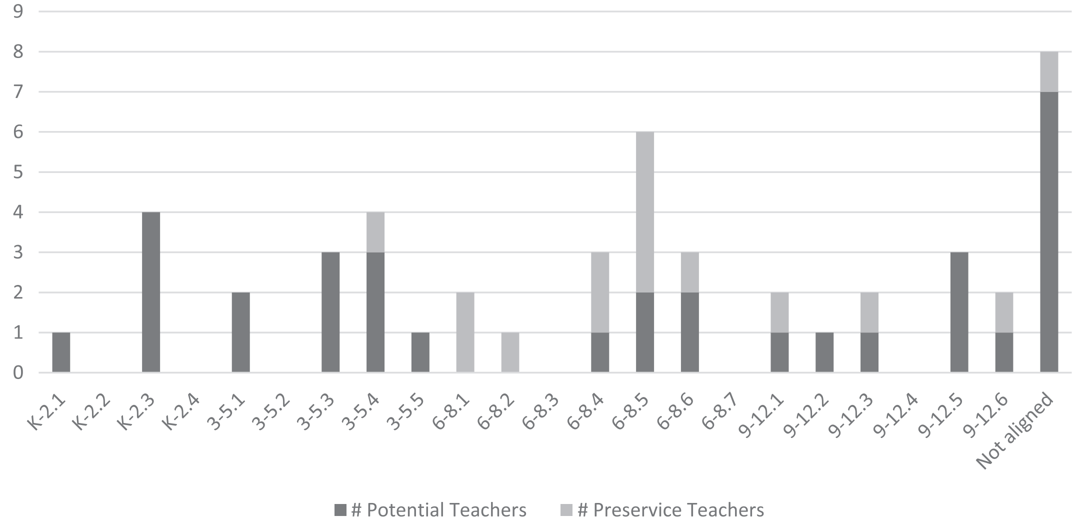

FIGURE 1 Number of potential and preservice teachers with excerpts coded for each competency code and not aligned code

> [the student] came up with the idea of making another box and putting something in it that they thought was in the original box.

In their discussion about a black box activity, the student suggested making a physical model to manipulate and test possibilities of what composed the system in the black box.

We close our first finding set by noting that seven potential teachers and one preservice teacher had at least one transcript excerpt coded as not aligned. In these instances, the participants described models and the practice of developing and using models in ways that did not align with the *NGSS* competencies. In particular, they commonly described models as student projects or as instructional tools. Three potential teachers from PBEA considered the engineering projects that PBEA students created as models. For example, in her mid-year interview, Erica said, "You could argue that building those projects is a model of what they've learned." She echoed this idea in her final interview as she referred to students' projects as models in which "they get to show off the science that they learned that year or the programming and engineering that they learned that year." Similarly, in his mid-year interview, Josiah explained that at PBEA "they [students] are doing a lot of developing and using models, and pretty much the whole project itself is one big model of how science works." In a similar way, in her final interview, Letitia described models as exemplar projects from previous students:

> So [students] are developing their own parts [of their project in the machine shop] … and at the same time they're using already made models as a basis for … what it should look like in the end …. The teachers have examples of what it should end up looking like.

These three potential teachers placed at PBEA thought of students' projects as models—as an instantiation of what students learned, an illustration of the scientific method, or as exemplars.

In contrast, three potential teachers placed at GSA described models and modeling as an instructional tool or practice—a tool or action that the teacher uses to help students. For example, in his mid-academic year interview, Sung defined a model as "a physical object that demonstrates an idea," explaining that "if the physical object can't demonstrate it [the idea] then it doesn't become a model anymore, it just becomes an object that you can interact with, but it might not really be helpful when you're trying to teach other people." He emphasized that "a model is supposed to help you learn something." He further commented that he did not think his mentor teacher used models "to help explain the physics concepts" because "most of it was just theoretical on paper … it wasn't using a model per se but more like theoretical problems of bowling balls." He thought that his mentor teacher was not implementing the practice of developing and using models because she was not using physical objects (like bowling balls) as examples. Yet, in his final interview, he recalled that his mentor teacher did use physical objects as models, such as a stuffed animal attached to the ceiling with a string to demonstrate forces. In both of these interviews, then, Sung understood models to be physical objects that teachers use as instructional tools to demonstrate concepts.

5.2 | Finding set 2: Comparisons between teacher groups and across practicum contexts

We found differences in understanding of the practice of modeling by group (i.e., potential vs. preservice teachers) and by practicum context (i.e., PBEA vs. GSA). Comparing across the potential and preservice teacher groups (see again

Figure 1), potential teachers described this practice in ways that resonated with competencies from all four grade bands. Indeed, potential teachers' descriptions of modeling were distributed fairly evenly across the four grade bands. In contrast, the competency codes applied to preservice teachers' descriptions fell mostly in the 6–8 and 9–12 grade bands. More specifically, of the nine competency codes used for preservice teachers' descriptions, five were in the 6–8 grade band and three were in the 9–12 grade band while only one was in the 3–5 grade band, and none were in the K–2 grade band. Further, there was a difference between the potential and preservice groups for the not aligned code. As mentioned in Finding Set 1, seven of the eight potential teachers had one or more excerpts about the practice of modeling that did not align with any competencies, whereas only one of the four preservice teachers did.

Comparing across practicum contexts, Figure 2 shows the distribution of codes separated for PBEA and GSA participants. Recall that there were equal numbers of participants at PBEA and GSA (six at each academy). Recall also that PBEA was a project-based engineering academy while GSA was an environmentally focused academy that included chemistry and physics courses in addition to an engineering course. As shown in Figure 2, the competency codes applied to PBEA participants' descriptions were relatively evenly distributed across the four grade bands. In contrast, the majority of competency codes applied to GSA participants' descriptions fell within the 6–8 and 9–12 grade bands, with few in the K–2 and 3–5 grade bands. Further, there was a noticeable difference in occurrence of competency 3-5.4: "Develop a diagram or simple physical prototype to convey a proposed object, tool, or process" (NGSS Lead States, 2013, Appendix F, p. 53). We clarify that the construct of prototypes is not included in any competency in the 6–8 or 9–12 grade bands. Four participants from PBEA described modeling as students working with prototypes and considered prototypes to be a type of model. No participants from GSA, however, described the practice of modeling or models themselves in this way. For example, when describing how he saw the practice of modeling implemented at PBEA, Josiah stated: "A lot of the projects that [students] do is them actually building prototypes and things, trying to work their way towards their end goal and seeing what [the prototypes] do." We see this difference in the mention of competency 3-5.4 to reflect an important difference between engineering and science: In engineering, models in the form of prototypes are routinely used to analyze and test designs.

As introduced in Finding Set 1, there were differences across practicum contexts with the not aligned code as well. Potential teachers from PBEA understood that students develop and use models, but they conceptualized models, in part, as students' final projects. This makes sense given that PBEA emphasized project-based learning. Potential teachers from PBEA thought that students engaged in this practice throughout the curriculum by designing and building projects. They considered students' final projects to be models of what students had learned, of the scientific process, or as exemplars for other students. In contrast, potential teachers from GSA understood the practice of modeling, in part, to be a teaching practice in which a teacher develops and uses models as instructional tools to help students learn.

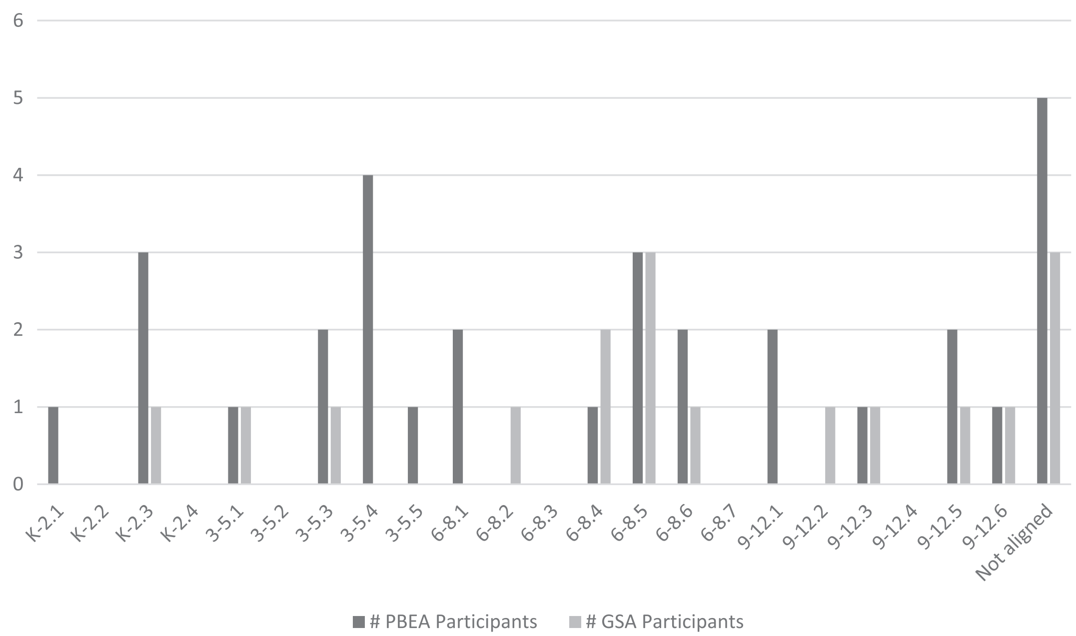

FIGURE 2 Number of PBEA and GSA participants with excerpts coded for each competency code and not aligned code

6 | DISCUSSION AND IMPLICATIONS

In contrast to previous studies that have elucidated teachers' general understanding and implementation of models and modeling in science instruction (Khan, 2011; Schwarz & Gwekwerere, 2007; Windschitl & Thompson, 2006), our study specifically determined how teachers' understandings aligned with the competencies for this practice detailed in the *NGSS* (NGSS Lead States, 2013). We found that undergraduate-level potential teachers and graduate-level preservice teachers working in two STEM-focused academies often described the practice of developing and using models in ways that resonated with various competencies in each of the four-grade band levels tied to the *NGSS*. However, they also expressed conceptions of the practice that were not aligned with the *NGSS*.

As stated in our Literature Review, the practice of developing and using models is complex and challenging for teachers to understand (Schwarz et al., 2009; Windschitl & Thompson, 2006). Our findings show that potential and preservice teachers understood this practice in multiple ways, with some ways being more and some being less scientifically accurate. It is important for teacher educators to recognize and draw from the diverse ways that beginning teachers conceptualize this practice so as to help them expand and deepen their overall understanding. In other words, teacher educators should view beginning teachers' understandings—both those that are already aligned with the *NGSS* and those that are not—as resources (Louca, Elby, Hammer, & Kagey, 2004) that can and should be built upon to expand and strengthen beginning teachers' knowledge and implementation of this practice.

As introduced in our Theoretical Framework, learning to teach is viewed as a continuum with distinct phases (Feiman-Nemser, 2001). In this study, we examined the understandings of beginning teachers at two points in the initial preparation phase: undergraduate potential teachers who were exploring teaching as a career and graduate preservice teachers enrolled in a teacher education program. As beginning teachers in different stages of the initial preparation phase, we expected their understandings and needs related to the practice of developing and using models to be different. Indeed, the potential teachers' conceptions were more evenly distributed across the four grade bands, whereas preservice teachers held conceptions that fell mostly in the 6–8 and 9–12 grade bands. Potential teachers also held more conceptions that were not aligned with the *NGSS* than their preservice teacher colleagues. Although differences in potential and preservice teachers' understanding were expected, these differences underscore the need to attend to the varying resources that teachers bring with them to the different stages of the learning continuum.

In addition to differences in understandings between the undergraduate and graduate groups, there were differences in understandings between participants placed at the two academy contexts. Using a situated view of learning, which foregrounds the contextual aspects of learning, each academy context was understood to uniquely impact participants' ideas about this practice. We found that participants placed at PBEA thought of models in an engineering sense (i.e., models as prototypes), whereas the participants placed at GSA did not (even those placed in an engineering course). PBEA had a clearer emphasis on engineering compared to GSA, using an integrated project-based engineering curriculum. Teachers need to understand both the scientific and engineering aspects of the practices specified in the *NGSS*. Practicum contexts that feature engineering instruction can help beginning teachers understand the engineering aspects of each practice by exposing them to how practices are conceptualized and used in engineering.

Another difference in understandings across practicum contexts was found with the not aligned code. Potential teachers at PBEA thought of the projects that students made as models. In an academy focused on projects and project-based learning, it makes sense that they would contextualize what a model is in terms of students' actual projects. Interestingly, three GSA potential teachers thought of models as instructional tools. Since all participants were placed in classrooms to learn about teaching, they might have considered the practice of modeling to include a teaching component in addition to a scientific or engineering component. However, it is unclear why this was more prevalent among participants at GSA than PBEA.

These differences found across the two practicum contexts have important implications for science teacher education. A variety of classroom contexts with mentors who understand and implement the *NGSS* practices may help science teachers in the initial preparation phase develop a greater breadth of understanding. This is especially important as implementation of the *NGSS* practices and inclusion of engineering become more widespread. Indeed, very few secondary science teachers have taken engineering courses themselves (Banilower et al., 2013). As such, beginning teachers will need experiences in engineering-rich classrooms to better understand the engineering side of the *NGSS* practices, including developing and using models.

7 | LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

We note that there are several limitations to our study. One limitation is that we investigated a small sample of potential and preservice teachers, and as such, we cannot determine if the differences we found between potential and preservice groups or between the PBEA and GSA academy contexts are statistically significant. A second limitation is that we used the competencies from the *NGSS* (NGSS Lead States, 2013) to analyze participants' descriptions of the practice of developing and using models; however, in our interviews, we asked participants to talk more broadly about this practice rather than specifically about each competency. In other words, had we presented participants with the list of competencies and asked them to give examples of how they had observed or implemented modeling in relation to each, they might have shared more or different ideas and examples. A third and related limitation is that the questions we asked about the practice were part of a longer interview. We might have elicited richer descriptions of modeling, and thus, more insight into potential and preservice teachers' understanding, if the interviews focused exclusively on this practice.

We suggest two important areas for future research stemming from our study. One area is to examine if and how potential and preservice teachers' understandings changed over time. Although we conducted interviews at various points in time throughout the academic year, participants varied in their length of participation in academy classrooms. As stated in the Methods, although all undergraduate potential teachers completed the five-week internship, six of the eight potential teachers continued to participate in academy classrooms after the five weeks, but did so to varying degrees. Thus, an analysis of change over time was too complex to include here but should be investigated in the future. A second area for future research is to examine how outside coursework or instruction contributed to participants' understanding. As described in the Methods, potential teachers attended a seminar during the five-week internship that focused on *NGSS*-aligned instruction, including the science and engineering practices. In contrast, the preservice teachers were required to take three science methods courses throughout the academic year as part of their credential program. Our finding that the graduate preservice teachers' conceptions fell mostly in the 6–8 and 9–12 grade bands is likely reflective of what they learned about the practice in their credential program courses. However, a more in-depth examination of the intersection of practicum experience with coursework is needed.

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